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Paleolimnology of Lake Isle, Alberta, Canada (Including sediment chemistry, pigments and diatom stratigraphy)

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With 14 figures and 2 tables in the text

Abstract

The paleolimnology of Lake Isle, Alberta, Canada (latitude 52°37′; longitude 114°26′) was investigated using sediment chemistry, pigments and diatom stratigraphy. Calcium, carbonates and iron fluctuations indicated that during the warm, dry hypsithermal period the lake became shallower. The lake, always productive, was most productive during this time. Also, diatom stratigraphy was limited to this period because before and afterwards numbers were too small to provide valid counts; moreover, those present were fragmented and too badly eroded. Benthic species (mainly *Fragilaria* spp.) initially dominated but were quickly replaced by planktonic species (e.g., *Stephanodiscus hantzschii, S. astraea, Cyclotella comta, Tabellaria fenestrata*). The volcanic ash from Mt. Mazama disrupted the natural aging process and benthic species assumed importance immediately afterwards (epipelic species). The post-hypsithermal period is characterized by little change.

Introduction

Lake Isle (latitude 52°37′; longitude 114°26′) is situated in an area of glacial till originating from the pre-cambrian shield deposited during the late Wisconsin period (Collins & Swan 1955). Originally it was part of a large lake resulting from melting ice (Rutherford 1928; Collins & Swan 1955). Deglaciation occurred between 13,500 and 10,000 years B.P. in that area (St. Onge 1972). Today, the lake is typical of many found in central Alberta, being both relatively shallow (Reynoldson 1977) (Fig. 1), and productive and eutrophic with large blue-green algal populations forming each summer (Hickman, unpublished data).

The purpose of this investigation was to provide an environmental history of the lake through examination of a sediment core utilizing chemistry, pigments and diatoms.

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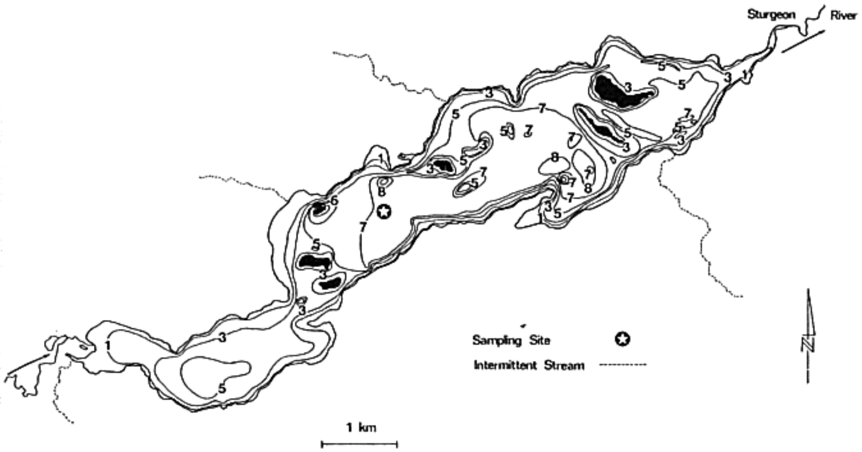

Fig. 1. A morphometric map of Lake Isle showing the coring site. Contours are in metres.

Methods

The coure was collected during the winter using a modified piston corer (Wright et al. 1965). The sampling site situation is shown in Fig. 1. Core sections (diameter and length 5.1 and 100 cm respectively) were extruded in the field to permit a cursory examination, detection of obvious contamination and measurement of the sample recovered. Each was wrapped, first in light plastic, and then with heavy brown paper which minimized exposure to light and air. All were maintained at 4 °C in the dark in the laboratory until sub-sampled.

Each section was remeasured and described with respect to composition, texture, structure and colour (Oyama & Takehara 1970). Afterwards 1 cc samples were removed for determinations of organic matter, water content and carbonates at 5 cm intervals. Water content was measured as weight loss after drying at 105 °C for 24 hr, organic matter after ignition at 550 °C for 1 hr, and carbonates after further ignition at 950 °C for 3 hr (Wetzel 1970). Further 1 cc samples were taken for fossil pigments and diatoms. Pigments were extracted in 15 mL 90 % acetone enhanced by first homogenizing the sediment with a Polytron-PCU-2-110 (Brinkman Instruments) followed by 24 h at 4 °C in the dark. The spectrophotometric methods of Moss (1967 a and b) were used. Results were expressed as S.C.D.P. units cc^{-1} and gm^{-1} organic matter. The samples for diatoms were treated with a mixture of concentrated sulphuric acid, potassium dichromate and hydrogen peroxide before repeated washings with distilled water to remove all traces of acid. Afterwards a known volume was pipetted onto a coverglass (18 mm diameter) and allowed to slowly dry. Each was then mounted in hyrax. Diatoms were identified according to Hustedt (1930, 1930—1966), Patrick & Reimer (1966, 1975) and Cleve-Euler (1951—1955).

For sediment chemistry 100 mg freeze-dried sediment was placed in the teflon cup of an acid digestion bomb, and subsequently digested in 1 ml aqua regia, and 5 ml 59 % hydrofluoric acid for 2 h at 135 °C. The digest was transferred, after cooling, to a 100 ml volumetric flask containing 2.9 g boric acid, and 20 ml deionized water. This was shaken to dissolve the boric acid, made up to 100 ml with deionized water and stored in acid-washed Nalgene bottles (LORING & RANTALA 1977). Calcium, iron, magnesium and manganese were determined by atomic absorption spectrophotometry, and sodium and potassium were analyzed flame photometry. Sulphate was determined turbidometrically but glycerol was omitted since it caused interference (ANON 1976; FORBES 1980; FORBES & HICKMAN, in press). Phosphorus was determined by the stannous chloride method and the stannous chloride reagent of MACKERETH (1963) used. 100 mg freeze-dried sediment was used for determination of nitrogen and extracted by micro-kjeldahl digestion and analysed using a Technicon autoanalyser.

Samples, 10 cm long, were also removed, freeze-dried, wrapped in foil, and sent to Dicarb Radioisotope Laboratores, Chagrin Falls, Ohio, U.S.A. for carbon-14 analysis.

Results

Core description

The core measured 655 cm. However, the upper 20 cm was too fluid to be reitained or sampled. It comprised clay gyttja. Above 400 cm no structure, bedding or laminations were detectable. Colour, too, varied little (5Y3/2 to 2.5Y3/2). Below distinctive colour bands ranging from 10Y3/1 to 2.5Y3/2 were present. Isolated carbonate particles first occurred at 314 cm but distinct bands not evident until 467 cm. Carbonate particles were most pronounced between 380—385, 515—530, and 560—580 cm. Volcanic ash originating 6600 years B. P. from Mt. Mazama (WESTGATE et al. 1969) occurred at 545 cm. Below 600 cm the clay content increased further, particularly between 630—636 cm. Then, among the clay near the base of the core, woody fragments along with a little gravel were found.

Chronology and sedimentation rates

Radiocarbon dates are presented in Table 1 along with the date placing the Mazama eruption at 6600 years B.P. (FRYXELL 1965; WESTGATE et al. 1969). A basal date of 9530 ± 120 years was obtained at 603—613 cm. Extrapolating, and assuming a constant sedimentation rate, to the core's base gives a date of 10,300 years B.P. at 655 cm. During the first 770 years existence the sedimentation rate averaged 0.61 mm yr^{-1}. It slowed to 0.22 mm yr^{-1} between 9580 and 6600 years only to more than triple between 6600 and 3910 years B.P. to 0.78 mm yr^{-1}. The period 8000 to 4050 years B.P. corresponds to the hypsithermal period previously reported by LICHTI-FEDEROVICH (1970) from her work upon Lofty Lake, Alberta. A further increase of 1.5 times occurred between 3910 and 1910 years B.P. (1.14 mm yr^{-1}) while during the last 1900 years the sedimentation rate averaged 0.57 mm yr^{-1}.

Table 1. Radiocarbon dates of sediment samples taken from Lake Isle.

Depth (cm)	Radiocarbon Date (^{14}C years B. P.)
102.5—110	1910 ± 40
330 —340	3910 ± 130
545	6600*
603 —613	9530 ± 120

* from Westgate et al. 1969.

Water content and organic matter

Sediment water content varied little except in the basal layer (Fig. 2 a). Initially low (≅ 26 % at 650 cm) it rose rapidly to 74 % by 625 cm. Thereafter, it slowly increased to about 350 cm. From here to 25 cm it remained similar. A minimum during the gradual increase occurred at 550—545 cm corresponding to the ash layer. The general sediment water content pattern is consistent with compaction of the deepest sediments (ADAMS & DUTHIE 1976).

Organic matter was also initially low (≅ 6 %) but from 635 cm it rose quickly reaching an early peak (47 %) at 620 cm (Fig. 2 a). This

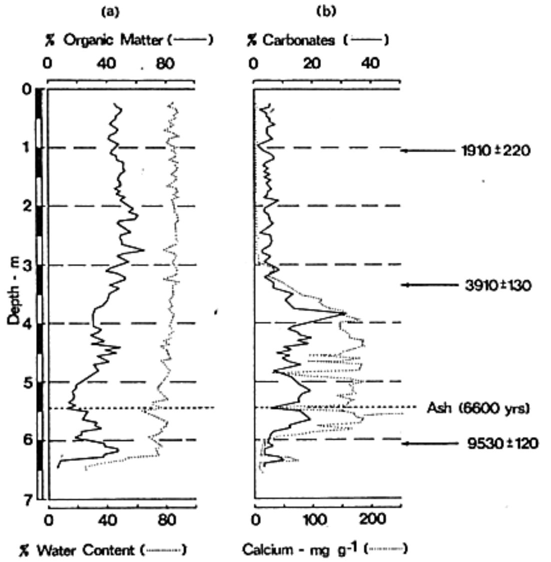

Fig. 2. (a) Percentage organic matter and the sediment water content and (b) percentage carbonates and calcium concentration (mg g^{-1} dry sediment).

was followed by first, a decrease, and then a minor peak at 580 cm (36 %). A minimum (12 %) corresponding to the ash layer occurred at 545 cm. Levels remained low until 505 cm, and increased to an irregular broad bulge between 465 and 440 cm (maximum 49.8 %). After a further decline the organic matter increased to the largest maximum at 275 cm (65.4 %). From here to 25 cm it gradually declined.

Carbonates and calcium

Carbonate concentrations within the upper 340 cm remained very similar, ranging from 1.5 to 8.5 % (Fig. 26), while between 345 and 565 cm they were far greater with major peaks at 385 cm (29 %), 425 (20 %), 435 (17 %), 515 (18 %) and 565 (19 %). A minimum occurred corresponding with the ash layer (Fig. 2 b). Below 595 cm values were low but similar to those within the upper 340 cm (except for a small peak at 635 cm).

Calcium levels followed those of carbonates (Fig. 2 b). Almost no change occurred within the upper 300 cm but a rapid increase occurred and high levels were maintained between 345 and 595 cm. More variability existed compared to carbonates but the overall close correspondence between carbonates and calcium suggests most was deposited as calcium carbonate.

Magnesium, sodium and potassium

Magnesium concentrations fluctuated little (Fig. 3 a). Generally, they decreased from 655 cm to around 300 cm, and then remained almost constant. A minimum coinciding with the ash occurred at 545 cm.

Sodium levels decreased slowly and irregularly from the core's base to 400 cm (Fig. 3 b). One major exception was the large peak at 545 cm corresponding to the volcanic ash. Above 400 cm two peaks occurred at 480 and 330 cm; then between 320 and 210 cm values were quite constant but afterwards a rapid increase followed which culminated in a broad maximum between 200 and 105 cm. From 100 to 25 cm levels were lower and similar to those between 320 and 210 cm.

Potassium levels were high at 655 cm, and then declined to a minimum between 580 and 550 cm (Fig. 3 c). Again, as with sodium, potassium levels dramatically increased in the ash layer at 545 cm. Afterwards, they decreased, at first rapidly, and then more slowly, reaching a minimum around 390 cm. From here to 25 cm values increased irregularly with slightly lower values between 200 and 115 cm.

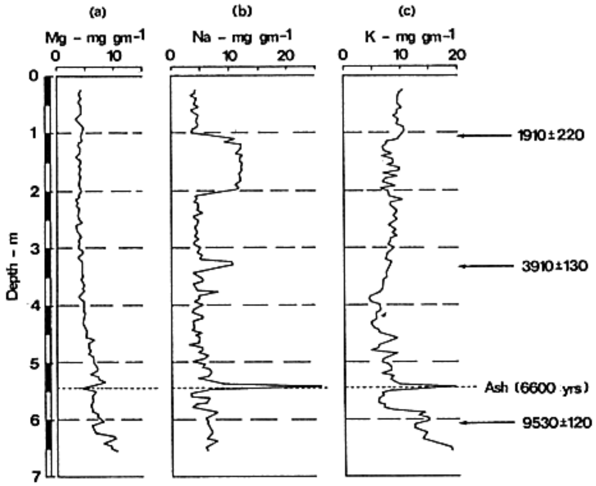

Fig. 3. The concentrations of (a) magnesium, (b) sodium, and (c) potassium (mg g^{-1} dry sediment).

Iron and manganese

Highest iron concentrations occurred in the basal sediments (Fig. 4). Afterwards, they decreased quickly reaching a minimum at 575 cm. Values declined slightly and irregularly to 390 cm. From here they increased with

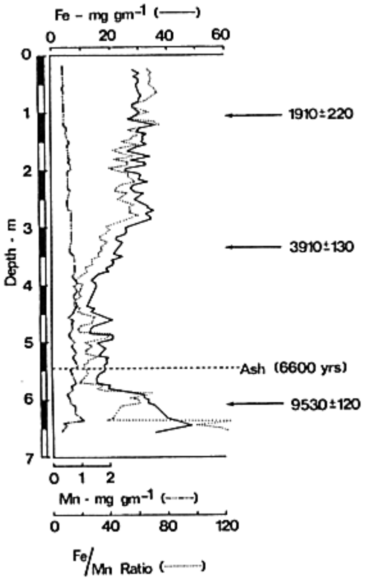

Fig. 4. The concentration of iron and manganese (mg g^{-1} dry sediment) and the Fe: Mn ratio.

a maximum being reached at 270 cm. Irregular fluctuations then occurred to 25 cm. Manganese levels, in contrast, fluctuated little (Fig. 4). However, highest levels were again within the basal sediments, and afterwards they decreased slowly. The Fe : Mn ratio followed the iron profile very closely (Fig. 4) with highest values in the basal sediments, and lowest between 570 and 390 cm, these reflecting the low iron concentrations during the period.

Phosphorus and nitrogen

Phosphorus levels slowly increased from the core's base to a maximum at 150 and 125 cm (Fig. 5 a). Above 125 cm they declined. Around the ash values were low but a peak occurred shortly afterwards at 530 cm. Expressed per gm organic matter found phosphorus levels fluctuating more, being high at the base declining to a minimum at 520 cm. The peak at 530 cm was greatly accentuated (Fig. 5 a). Afterwards the general trend followed that of phosphorus gm^{-1} dry sediment.

Total Kjeldahl nitrogen (TKN) increased from the base to a peak at 615 cm (Fig. 5 b). A further two peaks occurred at 575 and 555 cm before a minimum corresponding to the ash occurred. From here TKN concentrations increased steadily up the core. One peak and two noticeable minima occurred at 480, 330 and 215 cm respectively.

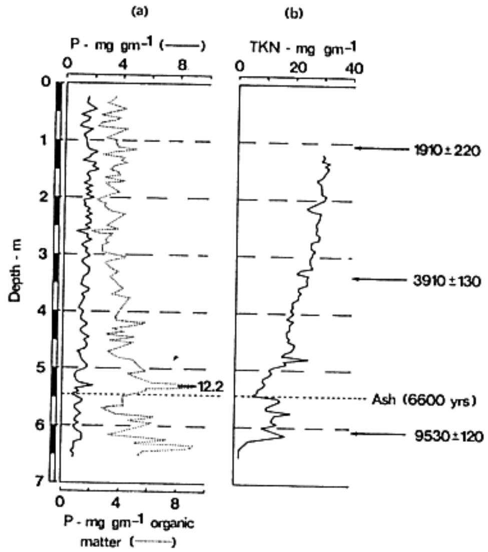

Fig. 5. The concentration of (a) total phosphorus (mg g^{-1} dry sediment and mg g^{-1} organic matter) and (b) total Kjeldahl nitrogen (TKN — mg g^{-1} dry sediment).

Sulphate

Maximum sulphate levels occurred between 125 and 275 cm (Fig. 6). Above concentrations declined, and stabilized at levels one half those of the maximum. From 275 cm downwards levels gradually declined to a minimum at 525 cm, after which they increased again peaking at 640 cm before declining rapidly to 655 cm.

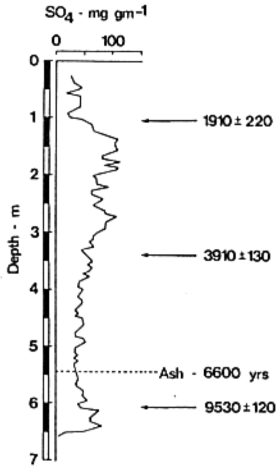

Fig. 6. The sulphate concentration (mg g^{-1} dry sediment).

Fossil pigments

Both total a pigments (TaP) and total carotenoids (TC) were initially low but from 630 to 610 cm they increased quickly (Fig. 7 a and b). A maximum occurred at 575 cm but was followed by decreases, after 545 cm in particular, corresponding to the volcanic ash. Maximum TaP and TC levels were found between 475 and 320 cm corresponding to the high carbonate values. From 320 to 25 cm both gradually fell. Expressed per gm organic matter provided a stratigraphy almost identical to the TaP gm^{-1} dry sediment (Fig. 7 c), while the TaP : TC ratio increased with decreasing sediment age to twin peaks at 165 and 150 cm before decreasing to a minimum at 90 cm. It then increased again to the largest maximum at 45 cm (Fig. 7 d).

Diatom stratigraphy

113 diatom taxa were found during the analysis (Table 2) but only a small number were present in sufficient numbers to indicate their stratigraphy (Fig. 8), and only between 275 and 610 cm. Above, and below,

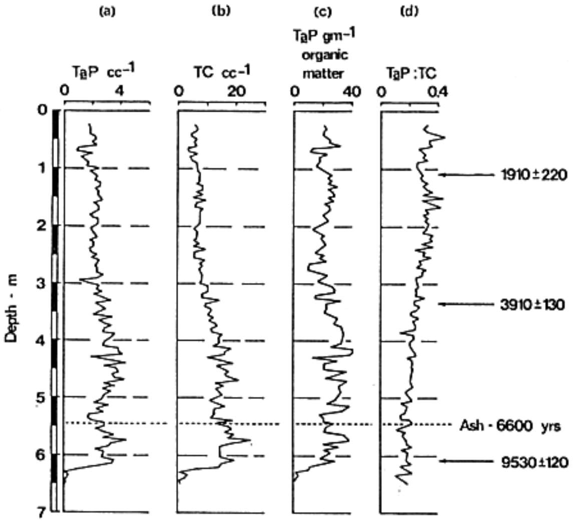

Fig. 7. (a) Total a pigments (TaP) and (b) total carotenoids (TC) (cc^{-1} wet sediment), (c) TaP gm^{-1} organic matter, and (d) TaP: TC ratio.

numbers were too small to provide valid counts. Moreover, many times none were found while those present were either badly eroded and/or fragmented into unrecognizable pieces, particularly within the upper 275 cm. Therefore, the stratigraphy presented covers a period from about 9800 to 3500 years B.P.

Stephanodiscus hantzschii dominated, even though its stratigraphy was irregular with a series of pronounced peaks at 585, 565, 550, 530—515, 495, 475—465, 445, 430, 420, 405, 380, 345, 335, 325 and 305 cm. *S. astraea* and *Melosira granulata* were also present throughout and displayed less variability. *S. astraea* was most important between 440 and 355 cm and *M. granulata* at 345 cm which coincided with a marked decrease of *S. hantzschii* (Fig. 8). It decreased afterwards, but a broader maximum occurred between 300 and 270 cm.

Cyclotella comta, *Tabellaria fenestrata* and *Asterionella formosa*, three other planktonic diatoms, all displayed more restricted distributions. The former two species were most prevalent early in the core (Fig. 8). *C. comta* peaked at 575 and 560 cm while *T. fenestrata* did so at 570 cm. Above *C. comta* peaked three times at 555, 485—480, and 460 cm while afterwards it was found only in tiny amounts whereas *T. fenestrata* was almost non-existant above 565 cm. *Asterionella formosa*, in contrast, was not encountered until 545 cm, and then only as small populations until peaks occurred at 485 and 310 cm (Fig. 8).

The other taxa are benthic diatoms. Initially, *Fragilaria brevistriata*, *F. construens*, *F. construens* v. *venter*, *Navicula oblonga*, *N. scutelloides*, *Amphora ovalis* and the varieties *libyca* and *pediculus*, and *Epithemia*

Table 2. Diatom species found in the Lake Isle core.

Achnanthes clevei Grun.
A. clevei V. *rostrata* Hustedt
A. conspicua A. Mayer
A. conspicua V. *brevistriata* Hustedt
A. exiqua Grun.
A. lanceolata Bréb.
A. haukiana Grun.
A. minutissima Kütz.

Amphora ovalis Kütz.
A. ovalis V. *libyca* (Ehr.) Cl.
A. ovalis V. *pediculus* Kütz.

Anomoeoneis sphaerophora (Kütz.) Pfitzner

Asterionella formosa Hass.
Ceratoneis arcus (Ehr.) Kütz.

Cocconeis disculus Schum.
C. placentula Ehr.

Cyclotella antiqua W. Smith
C. comta (Ehr.) Kütz.
C. Kutzingianum Thwaites
C. meneghiniana Kütz.

Cymbella affinis Kütz.
C. cistula (Hempr.) Grun.
C. cuspidata Kütz.
C. cymbiformis (Kütz.) V. H.
C. ehrenbergii Kütz.
C. heteropleura (Ehr.) Kütz.
C. mexicanum (Ehr.) Cl.
C. parva (W. Sm.) Cl.
C. sinuata Greg.
C. ventricosa Kütz.

Diatoma elongatum Agardh.

Diploneis oculata (Bréb.) Cl.

Epithemia argus Kütz.
E. intermedia Fricke
E. sorex Kütz.
E. turgida (Ehr.) Kütz.

Fragilaria brevistriata Grun.
F. capucina (Ehr.) Grun.
F. construens (Ehr.) Grun.
F. constriens V. *venter* (Ehr.) Grun.
F. crotonensis Kitton
F. leptostauron (Ehr.) Hustedt.
F. pinnata Ehr.
F. pinnata V. *lancettula* (Schum.) Hustedt.
F. vaucheriae Ralfs

Gomphonema acuminatum Ehr.
G. bohemicum Reichett et Fricke
G. constrictum Ehr.
G. gracile Ehr.
G. intricatum Kütz.
G. intricatum V. *pumila* Grun.
G. longiceps V. *subclavata* Grun.
G. parluvum Kütz.
G. olivaccum (Lyngb.) Kütz.
G. subtile Ehr.

Gyrosigma attenuatum (Kütz.) Rabh.

Hantzschia amphioxys (Ehr.) Grun.

Mastoglia elliptica Agardh.

Meridion circulare Agardh.

Melosira granulata (Ehr.) Ratfs.

Navicula accomoda

N. anglica Ralfs.
N. aurora
N. bacillum Ehr.
N. cari Ehr.
N. cryptocephala Kütz.
N. cuspidata Kütz.
N. dicephala V. *rostrata* Mayer
N. halophila (Grun.) Cl.
N. hungaria V. *capitata* (Ehr.) Cl.
N. lanceolata (Ag.) Kütz.
N. laterostrata Hustedt.
N. menisculus Schum.
N. menisculus V. *upsaliensis* (Grun.) Grun.
N. radiosa Kütz.
N. reinhardtii Grun.
N. scutelloides N. Smith
N. verecunda Hustedt.

Table 2 (continued).

Nitzschia amphibia Grun.
N. angustata (W. Sm.) Grun.
N. angustata V. *acuta* Grun.
N. fonticola Grun.
N. palea (Kütz.) W. Smith
N. recta Hamtzsch.
N. sigmoidea (Ehr.) W. Smith

Nedium dubium (Ehr.) Cl.
N. Kozlowii Mereschkowsky

Opephora martyii Heriband

Pinnularia gibba Ehr.
P. interrupta W. Smith
P. molaris Grun.
P. subcapitata Greg.

Rhoicosphenia curvata (Kütz.) Grun.

Rhopalodia gibba (Ehr.) O. Müll.

Stauroneis phoenicentron Ehr.

Stephanodiscus astraea (Ehr.) Grun.
S. astraea V. *minutula* (Kütz.) Grun.
S. hantzschia Grun.

Surirella biseriata Breb.
S. linearis V. *constricta* (Ehr.) Grun.
S. ovata Kütz.
S. ovalis Breb.

Synedra acus Kütz.
S. pulchella Kütz.
S. rumpens Kütz.
S. ulna (Nitzsch.) Ehr.

Tabellaria fenestrata (Lyngb.) Kütz.

argus were important, but by 585 cm all had decreased. Immediately succeeding the volcanic ash at 545 cm *F. construens* and v. *venter* produced a large maximum coinciding with decreases in *Stephanodiscus hantzschii*, *S. astraea* and *Cyclotella comta*. Attaching species (e.g., *Cocconeis placentula*, *Epithemia turgida*, and *Synedra ulna* displayed no defined pattern, except for the latter species which increased between 440 and 390 cm (Fig. 8).

Planktonic diatoms as a group were most common in the core which is not unexpected due to the location of the sampling site in a deep portion of the lake (Fig. 9 a). However, benthic algae intially constituted the major group (Fig. 9 b), particularly at 610, 595 and 575 cm. Further peaks are evident at 540 cm after the ash layer, 480, 460, 300 and 275 cm, even though the general trend from 540 to 275 cm is a decrease in the percentage contributed by benthic diatoms. Subdividing the latter assemblage into epipelic and attached (mostly epiphytic probably) diatoms emphasizes the importance fo the former community during the inital stages, after deposition of the ash, and at all benthic algal peaks, except at 360 cm when attached forms, *Cocconeis placentula* and *Synedra ulna* peaked (Fig. 9 c and d).

Numbers of diatoms cc^{-1} wet sediment as a measure of diatom production showed a general decline from a massive peak at 585 cm (Fig. 10). However, that decline was punctuated by a series of large peaks at 565, 525, 490, 475, 445, 385 and 325 cm. During the deposition of the ash onto the lake bottom diatom numbers were low but had decreased prior to ash deposition.

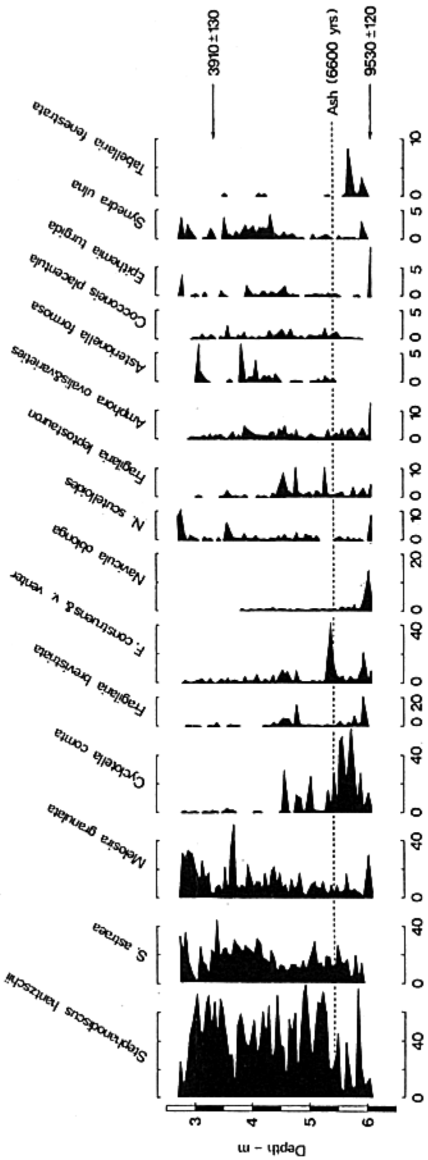

Fig. 8. Diatom stratigraphy.

Utilization of the diatom pH spectrum initially used by Hustedt (1937—1939) indicates that Lake Isle has been alkaline with high pH values throughout its entire history (Fig. 11). The largest number of diatoms are alkaliphilous but from around 400 cm the number of alkalibiontic forms increases. Correcting for the frequency of each species emphasizes

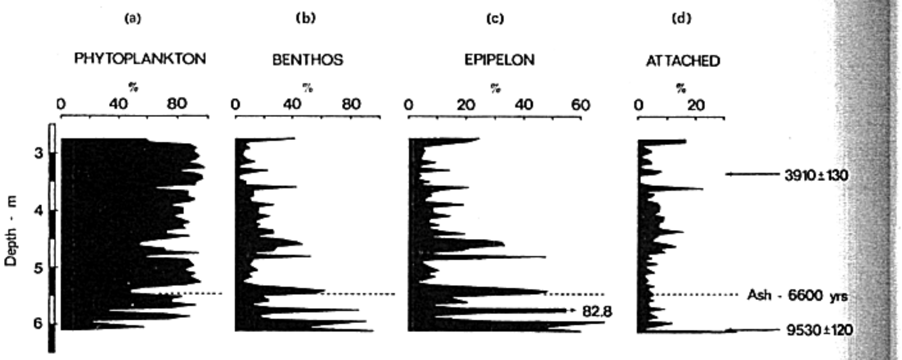

Fig. 9. Proportion of diatoms classified as (a) planktonic and (b) the benthic, (c) the epipelic and (d) attached.

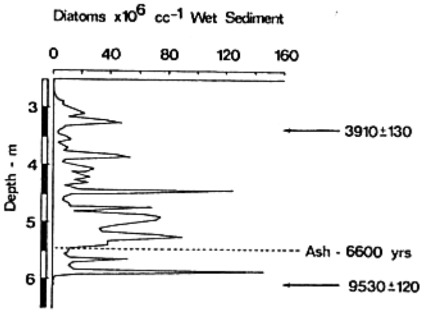

Fig. 10. The number of diatoms cc^{-1} wet sediment.

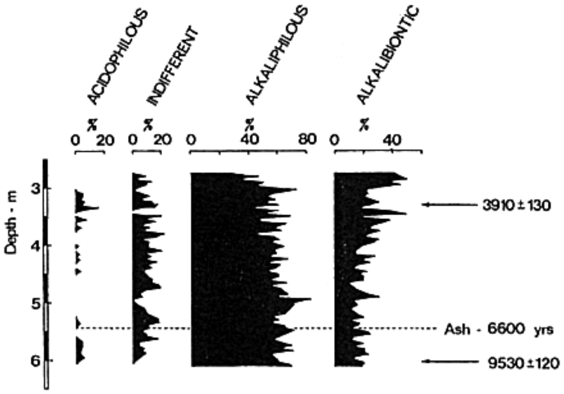

Fig. 11. The number of diatoms in each pH spectra grouping expressed as a percentage.

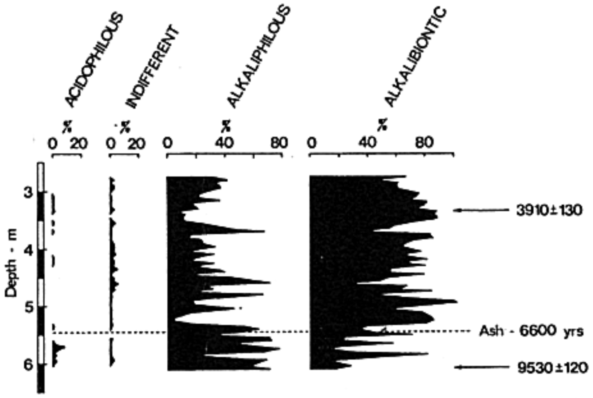

Fig. 12. pH spectra corrected for the actual number of individuals of each species.

the importance of the alkalibiontic group as they were most numerous, particularly after 545 cm (Fig. 12).

Discussion

Data from the Lake Isle core depict a paleoenvironmental history spanning approximately 10,300 years. The initial increase in organic matter coupled with declining magnesium, sodium and potassium levels indicates stabilization of the catchment area and lake since all are associated with the inorganic fraction, and hence erosion rates (Mackereth 1966). Phosphorus and nitrogen levels also lend support. Similarly, the diatom flora is representative of that period as benthic (mainly epipelic) species dominated (Fig. 9). These were soon replaced by planktonic species. *Fragilaria brevistriata, F. construens* and *F. construens* v. *venter* are characteristically found on shallow sediments, and *F. brevistriata* is dominant in the early developmental stages of some British lakes (Haworth 1969) while *Fragilaria* spp., in general, are commonly the pioneer diatoms encountered on lake sediments in European lakes as well as having been found in the outflow rivers of glaciers in Iceland (Haworth 1976), and upon lake sediments in other Alberta lakes (Hickman, unpublished data). The calcareous nature of the sediment is reflected by *Navicula oblonga* (Round 1953), and the presence of *Epithemia turgida* and *Synedra ulna* attests to the early development of aquatic plants.

During the initial phase a rapid increase in organic matter and total a pigments along with the diatom flora suggests the lake was eutrophic at a very early developmental stage (Ryback 1969; Hickman 1975). Certainly the TaP : TC ratio indicates eutrophy (Sanger & Gorham 1972). Also, the ratio gradually increases up the core to about 150 cm perhaps indicative of a gradual increase in allochthonous material and possibly a greater degree of aerobic decomposition of autochthonous organic matter. Even so, autochthonous deposition far exceeded allochthonous inputs throughout the entire history of the lake.

The rapid increase in both carbonates and calcium concentrations approximately 8000 years B.P. were due undoubtedly to falling water levels due, in turn, to the warmer, drier climate of the hypsithermal period (Richardson 1969). Also, biological production of calcium carbonate increases in shallower, warmer waters (Bortelson & Lee 1972). During this period the lake was indeed productive since total a pigment were highest throughout the hypsithermal period as was the TaP : organic matter ratio. It is unlikely, however, that the increase in the TaP : organic matter ratio is enough to account solely for such a marked increase in calcium carbonated deposition. In a dicarbonate rich lake such as Lake Isle increased evaporation rates, and decreased outflow could cause precipitation of excess carbonate as calcium carbonate. Hence, the warmer, much dryer climate of the hypsithermal period could be mostly responsible for the marked increase in both calcium and carbonate levels. The pollen record provides further evidence for both the hypsithermal period and lowered lake levels because both Gramineae and *Artemisia* pollen increase (c.f. Lichti-Federovich 1970), and *Ruppia occidentalis* pollen is evident at 530—535 cm (Schweger & Habgood, unpblished data). This latter plant is only found in the more saline, high conductivity Alberta lakes today.

The soils within the catchment area were more oxidized during the hypsithermal period than before or afterwards because of the lower iron concentrations found in the lake sediments. Iron in the oxidized state is insoluble (Mackereth 1966) while manganese parallels iron but remains reduced a higher oxygen levels. Since the various metals do not indicate a decline in erosion rates during the hypsithermal, decreased iron levels did not arise from decreased erosion rates. Also, manganese levels remained fairly steady. Therefore, catchment area soils during the hypsithermal period were in an oxidized state affecting iron but not manganese solubility.

The volcanic ash disrupted tha natural aging process of the lake since organic matter and TaP above the layer declined; thus lake productivity declined probably due to reduced light penetration and/or simple isolation of the lake water from the sediments which prevented leaching and diffusion of nutrients from the sediments back into the water (Barsdate & Dugdale 1972). Further disruptive evidence stems from the diatom record as benthic species (*Fragilaria construens* and *F. construens* v. *venter*) dominated immediately afterwards. Planktonic species (*Cyclotella comta* and *Stephanodiscus hantzschii*) declined dramatically.

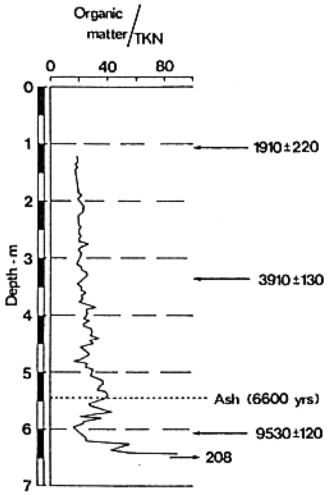

Fig. 13. The organic matter: TKN ratio.

The decline in both carbonates and calcium levels at about 4,000 years B.P. coincided with an increase in *Populus* and a decline of *Artemesia* pollen (c.f. Forbes 1980; Forbes & Hickman 1978) indicative of a shift to cooler wetter conditions. Water levels now began to rise. Deposition rates nearly doubled and diatom numbers diminished and those present were mostly unrecognizable. Concomitant with these changes iron levels increased thus the soils of the catchment area became more reduced. Productivity, as indicated by TaP and TC, decreased. However, the organic content of the sediment first increased then decreased, and the organic matter : TKN ratio indicates a gradual increase in lake productivity (Fig. 13) (Russell-Hunter 1970).

Relatively little change occurred during the post-hypsithermal period in either the lake or catchment area. Forbes & Hickman (1978, in press) reported a similar stability in a lake which closely neighbours Lake Isle. Productivity, although less than during the hypsithermal period was stable, and both phosphorus and nitrogen to organic matter have not altered significantly. The short period of high sodium levels had no detectable effect upon the lake while the decline in sulphate within the upper 100 cm could be due to sulphate reducing bacteria (Adams & Duthie 1976), particularly during the winter. The absence of diatoms in significant number during the period could be related directly to increased beposition rates (Fig. 14), turbulence, hence their eroded and fragmented appearance or to reduced population sizes, and a marked shift to communities, particularly the plankton, being dominated by blue-green and green algae. However, a diatom such as *Stephanodiscus hantzschii* will develop

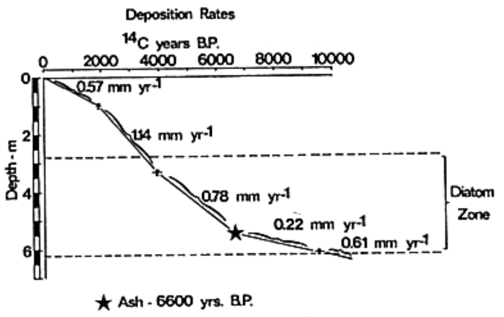

Fig. 14. Deposition rates. Also shown is the zone containing diatoms.

in lakes, characterized by large summer blue-green and green algal standing crops, during the spring, and even under ice-cover (Hickman 1979). Thus, physically disruptive factors seem more important.

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Zusammenfassung

Die Paläolimnologie des Isle-Sees, Alberta, Kanada (52° 37 min n. Br., 114° 26 min w. L.), wurde auf Grund von chemischen Untersuchungen der Sedimente und ihres Pigmentgehaltes sowie der Diatomeen-Stratigraphie ermittelt. Aus den Änderungen des Calcium-, Carbonat- und Eisengehaltes ergab sich die Schlußfolgerung, daß der See in der warmen, trockenen, hypsithermalen Periode flacher wurde. Das Gewässer war immer produktiv, erreichte aber seine größte Produktivität in dieser Zeit. Die stratigraphischen Untersuchungen der Diatomeenverteilung in den Sedimenten mußte auf diesen Zeitabschnitt beschränkt werden, weil oberhalb und unterhalb dieser Sedimentzonen zu geringe Diatomeenmengen vorhanden waren, als daß die Zählung erfolgreich durchgeführt werden konnte. Außerdem waren die restlichen Diatomeenfrusteln stark fragmentiert und recht stark erodiert. Benthische Diatomeenarten, vor allem *Fragilaria* spp., dominierten anfänglich, wurden aber bald durch planktische Arten ersetzt (z. B. *Stephanodiscus hantzschii, S. astraea, Cyclotella comta, Tabellaria fenestrata*). Die vulkanische Asche vom Mt. Mazama unterbrach den natürlichen Alterungsprozeß des Sees, und benthische Arten, auch epipelische, erreichten unmittelbar danach wiederum stärkere Entwicklung. Die nach-hypsithermale Periode weist nur geringe Änderungen auf.

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Excretion and DOC utilization by *Oscillatoria rubescens* D. C. and its accompanying micro-organisms

By Tsang-Pi Chang

With 7 figures and 1 table in the text

Abstract

Excretion and DOC utilization were measured in time course using the ^{14}C-method with O. *rubescens* and two *Synechococcus* species. A range of 4—6 % PER was measured for these red-colored cyanophytes. Three patterns of excretion were observed. It is proposed that carbon dioxide is the main exudate component for these 3 species. Most DOC that is produced is of a low molecular weight, a feature particularly true for O. *rubescens*. In contrast to O. *rubescens* which can utilize only its own exudates, *Synechococcus* has the ability to use large quantities of exudates self-produced or from other sources so enabling them to outgrow O. *rubescens* either in culture or in nature.

Oscillatoria rubescens which often causes water blooms, particularly in Alpine lakes (Zimmermann, 1969), can produce extracellular organic substances which always include a proportion of mucilage (Chang, 1979, 1980 a). Some accompanying microorganisms can stimulate this cyanophyte to produce excess mucilage which they subsequently assimilate. Such partners normally do not affect the growth of O. *rubescens* e.g. in 51-P cultures (Meffert & Chang, 1979). However, a recession phenomenon in two clonal cultures (216 A and 216 B, see Chang, 1980 b) has been recently observed. In these cultures O. *rubescens* can exist for a prolonged period only when its trichomal number in nutrient solutions is high and the density of accompanying microorganisms is relatively low. Such growth recession of O. *rubescens* in cultures and even in nature is probably caused by overgrowth of these accompanying microorganisms rather than by nutrient deficiency (cf. Lange, 1974). Growth of *Oscillatoria* species e.g. O. *redekei* (Meffert & Chang, 1978) can be stimulated when its growth-inhibiting exudate has been decomposed by accompanying bacteria (Herbst, 1976). O. *redeki* therefore grows better in bacteria-contaminated cultures than in axenic ones (Meffert & Chang, 1978). A metabolic coupling is proposed to be operative between these cyanophytes and their accompanying bacteria in culture and also in nature (Herbst & Over-

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